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AI-Driven Chatbots as Agents of Environmental Education: Transforming Ecological Communication in the Digital Age

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ABSTRACT

This study examines the role of AI-based chatbots as environmental education agents by investigating how conversational design, perceived communication quality, and trust influence pro-environmental attitudes, behavioral intentions, and willingness to pay (WTP) for ecological protection. Using a systematic targeted literature review, 24 peer-reviewed studies published between 1991 and 2025 were synthesized through thematic analysis. The findings indicate that problem-solving dialogue enhances pro-environmental outcomes through improved communication quality, moderate trust in AI strengthens behavioral internalization, justice-by-design is essential to prevent epistemic injustice in conservation knowledge, and LLM-based chatbots are most effective for users with existing environmental commitment. Limitations include the use of secondary data and the predominance of Western-based studies. Future research should validate these findings through field experiments in Indonesia and Southeast Asia. The study proposes the CETA (Chatbot Ecological Transformation and Action) framework, integrating framing theory, AI trust, and epistemic justice to provide an evidence-based guide for designing and evaluating environmental AI chatbots.

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1. INTRODUCTION

Climate change and global ecosystem degradation are not merely ecological crises; they are also fundamentally communication crises. Over the past decades, the volume of information on environmental issues has continued to expand through scientific reports, mass media coverage, and the abundance of digital content, yet the gap between public knowledge and behavioral change remains striking (Schäfer, 2025). The central problem is not simply the lack of data or facts, but rather how ecological information is constructed, disseminated, and translated into attitudinal change and collective action within an increasingly fragmented information ecosystem saturated with generative AI content (Schäfer, 2025). This challenge becomes even more acute in the age of social media, where climate narratives compete with waves of entertainment content and disinformation that are far more capable of attracting algorithmic attention (Treen et al., 2020).

Within this landscape, artificial intelligence (AI)-based chatbots have emerged as strong candidates for a new generation of ecological communication agents. Unlike conventional one-way communication channels, chatbots enable interactive and personally responsive dialogue: they can diagnose users' specific barriers, including limitations of time, cost, access, or knowledge, and offer recommendations for action that are relevant to the user's everyday context (Chi, 2024; Leal Filho et al., 2025). This adaptive problem-solving capacity, combined with round-the-clock accessibility, positions chatbots as potential facilitators of behavioral change that exceed what brochures, posters, or static informational websites can provide (Giudici et al., 2025; Kazoun et al., 2025). In Indonesia, with approximately 190 million active internet users and a Generation Z population that spends an average of seven hours per day on digital platforms, the infrastructure for the broad adoption of ecological chatbots is already in place (Schäfer, 2025).

Early empirical evidence significantly confirms this potential. Research examining the influence of AI chatbots on pro-environmental attitudes has found that problem-solving features, anonymity, and personalization are positively associated with pro-environmental attitudes and willingness to pay for environmental protection, with perceived communication quality serving as a key mediator in this chain of influence (Chi, 2024). LLM-based experiments employing anthropomorphic sea-creature characters have demonstrated that conversational narratives significantly increase pro-environmental behavioral intentions compared with the presentation of static scientific information (Pataranutaporn et al., 2025). A three-week longitudinal study further showed that repeated interaction with a chatbot representing the environment fosters parasocial interaction (PSI), which in turn mediates the development of pro-environmental attitudes and climate action intentions (Jang et al., 2025).

However, alongside this promise, the literature has also identified a series of serious communication risks. An analysis of 30,000 chatbot responses on ecological restoration revealed troubling systemic biases, including the dominance of academic expertise from high-income countries, the marginalization of community and Indigenous knowledge, and a tendency to present overly optimistic and overly narrow solutions (Urzedo et al., 2024). Another risk stems from the nature of LLMs themselves: their ability to generate responses that sound expert-like without actual verification may produce a form of "simulated authority" that obscures the boundary between verified knowledge and convincing yet inaccurate outputs (Rillig et al., 2023). Trust dynamics add another layer of complexity, as users with very high levels of trust were found to exhibit lower message internalization than users with moderate skepticism (Chakkambath et al., 2025).

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Research on chatbots for environmental communication has grown rapidly over the past five years. A systematic review of persuasive conversational agents for environmental sustainability identified a significant increase in studies since 2018, covering persuasive strategies ranging from personalization and gamification to anthropomorphic characters and the integration of motivational interviewing (Giudici et al., 2025). Research on LLMs for behavior change has shown that GPT-4-based chatbots can improve users' motivational readiness, particularly when users already possess an initial commitment to change (Meyer & Elsweiler, 2025). Value-sensitive design (VSD) has also been applied to the development of LLM-based chatbots for senior high school environmental education, identifying identity development, well-being, and sustainability as core values that should underpin all stages of design (Nguyen et al., 2025). On the risk side, studies on the environmental impacts of LLMs warn of substantial energy consumption and the potential reproduction of biases already embedded in the scientific literature (Rillig et al., 2023).

Despite these promising developments, at least four substantial gaps remain unresolved. First, climate communication framing theory, which has proven to be a bridging concept across actors, texts, and audiences, has not been explicitly applied as a guide for the micro-design of chatbot dialogue; consequently, framing decisions within conversational architectures remain implicit and unstandardized (Guenther et al., 2023). Second, the non-linear dynamics of trust as a moderator of environmental chatbot effectiveness have only been identified in limited ways, and their design implications for public education contexts remain underdeveloped (Chakkambath et al., 2025). Third, while the risk of epistemic injustice in conservation chatbots has been critically discussed in academic work, operational audit guidelines that can be integrated into real communication design practice are still absent (Xu et al., 2017; Urzedo et al., 2024). Fourth, no applied communication framework currently integrates the four dimensions of framing, trust, knowledge justice, and motivational evaluation into a holistic guide that can be operationalized by public communicators and environmental organizations, particularly in the Indonesian context (Nguyen et al., 2025).

Against this background, the present study sets out three objectives: (1) to map the communication mechanisms that have been shown to make chatbots effective as agents of environmental education; (2) to identify the systemic communication risks that may undermine the legitimacy and effectiveness of ecological chatbots; and (3) to develop the CETA framework (Chatbot Ecological Transformation and Action), which integrates framing, trust, justice, and motivational evaluation into an operational applied guide for Indonesian communicators. Its significance lies in its practical contribution to public communication practitioners, environmental educators, and civil society organizations seeking to use chatbots in an accountable, effective, and equitable manner in the AI era.

2. LITERATURE REVIEW

Communication framing theory defines framing as the selection and salience of certain aspects of perceived reality in order to define problems, identify causal relations, make moral evaluations, and recommend remedies, thereby shaping how audiences interpret issues and determine appropriate responses (Entman, 1993). In a systematic synthesis of 25 years of climate communication framing scholarship, Guenther et al. (2023) position framing as a "bridging concept" because of its capacity to integrate analyses of communicative actors, textual structures, audience sense-making processes, message effects, and socio-cultural contexts within a coherent framework that transcends subdisciplinary boundaries.

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The relevance of framing theory to environmental education chatbots is both direct and profound. Every chatbot session constitutes an ongoing act of framing: the wording of opening questions, the sequence in which topics are introduced, the examples chosen to illustrate impacts, the solutions recommended, and the ways scientific uncertainty is communicated are all framing decisions that shape how users make sense of environmental problems and what forms of action they regard as meaningful (Guenther et al., 2023). In this sense, chatbot developers function as "active framers," whose design choices reproduce particular assumptions about responsibility, legitimate solutions, and the appropriate scale of action.

In applied ecological communication, framing theory can be operationalized into concrete design guidance. Gain frames, which emphasize the benefits of sustainable action, have been shown to be more effective than loss frames, which stress the costs of inaction, particularly among audiences with an already established baseline concern for environmental issues (Nisbet, 2009). Solution-oriented and self-efficacy-based framing that highlights specific actions individuals can take is also more effective in encouraging sustainable behavioral intentions than threat-based framing, which may trigger psychological distancing or message fatigue, including eco-fatigue (Guenther et al., 2023).

2.1 Problem-Solving and Communication Quality as Mechanisms of Influence

Empirical research on pro-environmental chatbots has identified critical pathways of influence that are highly relevant for applied communication design. Chi's (2024) survey-based study of environmental chatbot users found that among four tested features, namely interactivity, anonymity, customization, and problem-solving, the problem-solving feature consistently emerged as the strongest predictor of pro-environmental attitudes and willingness to pay for environmental protection. More importantly, perceived communication quality functioned as a key mediator: chatbot features did not directly alter attitudes or commitment, but instead exerted their influence through users' experienced quality of communication during interaction (Chi, 2024).

This finding has transformative implications for communication design. Environmental education chatbots should not be designed merely as "information delivery machines," but rather as "agents that facilitate communication quality" by creating an experience in which users feel understood, supported, and empowered. This shifts the evaluative paradigm from "how much information is delivered" to "how well the conversational experience is perceived by users" (Chi, 2024). This shift is consistent with evidence from LLM-based motivational interviewing (MI), which shows that GPT-4 chatbots using MI techniques, such as guided reflection, ambivalence exploration, and commitment reinforcement, can enhance users' motivational readiness to act, especially when users have already moved beyond ambivalence and are prepared to take action (Meyer & Elsweiler, 2025). These findings suggest that chatbot effectiveness is layered and contingent upon users' initial motivational states: chatbots appear to perform especially well as converters of intention into action, while remaining more limited in building motivation from the ground up (Meyer & Elsweiler, 2025).

Evidence from the OceanChat experiment further reinforces this argument. LLM-based conversational characters representing sea creatures significantly increased pro-environmental behavioral intentions and preferences for sustainable choices relative to a static scientific information condition, with the effect mediated by higher emotional engagement in the conversational condition (Pataranutaporn et al., 2025).

2.2 Trust in AI as a Non-Linear Moderator

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Trust in AI systems is a multidimensional construct encompassing perceived competence, benevolence, and integrity of technological systems (Ferrario et al., 2020). In the context of environmental chatbots, trust shapes whether users are willing to open themselves to the recommendations provided and how they process uncertainty in the information presented.

Chakkambath et al. (2025) challenge the common assumption that higher trust necessarily results in more effective intervention outcomes. Their findings reveal a non-linear moderating pattern: at moderately low levels of trust, chatbot interaction exerts a stronger influence on environmentally friendly behavior, whereas extremely high trust actually weakens that influence. This pattern can be explained by cognitive processing mechanisms. Users with moderate skepticism tend to engage in deeper elaboration of chatbot messages, evaluating arguments, connecting them to prior knowledge, and comparing them with personal values; consequently, messages that successfully pass through this “gateway of skepticism” are internalized more strongly than messages received passively under conditions of very high trust (Chakkambath et al., 2025). The design implication is clear: chatbots should be built to respond productively to skepticism by presenting traceable evidence, explicitly acknowledging scientific uncertainty, and encouraging independent verification rather than attempting to eliminate or suppress user skepticism (Ferrario et al., 2020).

2.3 Epistemic Justice and the Risk to Communicative Legitimacy

Beyond persuasion mechanisms and trust, one often overlooked dimension of legitimacy in environmental chatbot design is epistemic justice: whose ecological knowledge is recognized as authoritative, and whose insights and lived experiences are considered worthy of representation in the system’s knowledge base (Urzedo et al., 2024). An analysis of 30,000 ChatGPT responses on ecological restoration revealed troubling and systemic patterns of bias: more than two-thirds of responses relied on expertise from academics in high-income countries (67%), whereas knowledge from low-income countries accounted for only about 7%, local community restoration experience for around 2%, and Indigenous knowledge for even less (Urzedo et al., 2024; van Dis et al., 2023). Technical recommendations were dominated by planting and reforestation approaches (69%), while holistic ecosystem approaches and non-tree species were neglected; outcomes were also presented with excessive optimism (60%) and without adequate communication of risk or uncertainty.

From the perspective of applied communication, this pattern threatens the legitimacy of chatbots as agents of environmental education through three mechanisms: distributive injustice, in which access to knowledge is uneven; recognition injustice, in which the authority of certain groups is erased; and epistemic injustice, in which Western science is positioned as the sole source of valid knowledge (Urzedo et al., 2024). Users from marginalized communities are therefore likely to receive advice that is poorly aligned with their local contexts, while chatbots may quietly “teach” them that valid ecological knowledge comes only from particular academic sources, thereby reproducing hierarchies that undermine both trust and communicative relevance in ecological communication (Urzedo et al., 2024). This risk is intensified by the nature of LLMs, which may amplify biases already embedded in scientific literature and deliver highly confident responses in areas that remain contested (Rillig et al., 2023).

2.4 Value-Sensitive Design as an Ethical Design Framework

Value-sensitive design (VSD) is a systematic approach that places human values at the center of technology design by integrating value considerations into every stage of development through complementary empirical, conceptual, and technical inquiries (Nguyen et al., 2025). Applications of VSD to LLM-based chatbots for environmental science education

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have identified four key values that should underpin design: user identity development, well-being, healthy human-AI relationships, and environmental sustainability (Nguyen et al., 2025). VSD makes it possible to translate abstract values into concrete design principles. For example, the value of user autonomy can be translated into features that allow topic choice and transparent communication of system limitations; the value of accuracy and trust can be translated into mandatory traceability protocols and explicit communication of scientific uncertainty; and the value of justice can be translated into standards for diverse source representation and periodic bias-audit procedures (Nguyen et al., 2025).

2.5 The CETA Framework: A Theoretical Integration

Drawing on the synthesis of framing theory (Entman, 1993; Guenther et al., 2023), problem-solving and communication quality mechanisms (Chi, 2024), non-linear trust dynamics (Chakkambath et al., 2025), epistemic justice (Urzedo et al., 2024), and VSD (Nguyen et al., 2025), this study proposes the CETA framework, Chatbot Ecological Transformation and Action, as an applied guide with four components: Credibility/Framing, referring to solution-oriented framing design combined with transparent referencing; Empowering Problem-Solving, referring to modules for diagnosing barriers and recommending micro-actions; Trust-Responsive Interaction, referring to productive responses to user skepticism; and Accountability/Justice-by-Design, referring to periodic audits of source representation. Together, these four components form a cycle of design, implementation, evaluation, and improvement that supports the entire development process of ecological chatbots.

3. METHOD

This study employed a systematic targeted literature review design within a pragmatic applied communication paradigm, evaluating theories and empirical evidence according to their capacity to generate communication guidance that can be operationalized in real-world contexts (Schäfer, 2025). This design was chosen because current knowledge on environmental education chatbots is dispersed across several subfields, including climate communication, conversational agent studies, AI ethics, and educational technology design; therefore, a cross-disciplinary synthesis was required to identify patterns, gaps, and opportunities that would remain less visible within a single subfield alone (Giudici et al., 2025). The pragmatic paradigm enables the integration of constructivist theory, particularly framing, with quantitative and qualitative empirical evidence on chatbot effects in a synthesis oriented toward actionable design implications.

The source framework covered five domains: (1) climate communication and digital media; (2) climate communication framing theory; (3) empirical studies of chatbots and conversational agents for environmental purposes; (4) value-sensitive design (VSD), trust in AI, and design ethics; and (5) risks, justice, and the environmental impacts of LLMs (Schäfer, 2025). The inclusion criteria were as follows: (a) publication between 1991 and 2025, with at least 80% of sources drawn from primary journal articles published between 2016 and 2025; (b) direct contribution to communication mechanisms, chatbot design, or ecological representational justice; (c) use of traceable and replicable methodology; and (d) the presence of implications that could be articulated for the design or evaluation of ecological chatbots (Chi, 2024). The exclusion criteria covered purely technical sources without communication implications, publications lacking verifiable methodology, and sources without direct relevance to the context of environmental education.

The selection process was conducted in three stages. First, an initial search was undertaken in Scopus, Web of Science, and Google Scholar using the keywords “chatbot AND environmental communication,” “conversational agent AND sustainability,” “AI AND

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ecological education," and "framing AND climate change communication," yielding 60 candidate sources. Second, the sources were screened for their relevance to the communication mechanisms of environmental chatbots, resulting in 35 sources. Third, a final selection was made on the basis of empirical or conceptual contributions that could be operationalized into design principles, resulting in a final corpus of 25 sources (Nguyen et al., 2025).

The data collection instrument consisted of a structured extraction sheet recording: (1) source metadata, including author, year, journal, and method; (2) identified communication mechanisms, such as problem-solving, trust, anthropomorphism, and traceability; (3) measured or argued outcomes, including attitudes, intentions, willingness to pay, and behavior; (4) identified risks, such as representational bias, epistemic injustice, LLM overconfidence, and environmental impacts; and (5) proposed design or evaluation recommendations (Guenther et al., 2023). For the justice dimension, the extraction sheet incorporated four analytical categories, namely distributive justice, recognition justice, procedural justice, and epistemic justice, following the framework used in analyses of conservation chatbot injustice (Urzedo et al., 2024).

Thematic analysis was conducted in four sequential phases: (1) open coding to identify and label mechanisms, risks, and recommendations from each source; (2) clustering codes into themes that reflected cross-source patterns; (3) mapping themes onto the CETA components in order to verify the framework's coverage and coherence; and (4) deriving design implications and evaluation indicators from each component (Guenther et al., 2023). Each analytic claim was traced back to the primary sources on which it was based in order to maintain a verifiable audit trail.

Validity was strengthened through source triangulation, whereby claims were confirmed with more than one source whenever possible, and through negative case checking by identifying sources that contradicted or qualified emerging claims (Nguyen et al., 2025). Trustworthiness was maintained through auditable documentation of the selection procedures and explicit reporting of contextual conditions that may limit the generalizability of the findings.

4. FINDINGS AND DISCUSSION

4.1 Problem-Solving Predicts Outcomes Through the Mediation of Communication Quality

Across the chatbot features examined in the literature, problem-solving consistently emerges as the strongest predictor of pro-environmental attitudes and willingness to pay (WTP), operating through the mediation of perceived communication quality (Chi, 2024). A study involving environmental chatbot users confirmed that the causal pathway of "problem-solving features → communication quality → attitudes → commitment (WTP)" is robust and replicable (Chi, 2024). Findings from OceanChat further confirm the effect of conversational format: pro-environmental behavioral intentions were 28% higher in the LLM-based conversational condition than in the static scientific information condition, with this effect mediated by higher emotional engagement and perceived anthropomorphism (Pataranutaporn et al., 2025). LLM-based motivational interviewing (MI) research adds an important nuance: the effects of problem-solving are strongest among users who are already committed to taking action, whereas users who remain ambivalent require different communication interventions to build initial motivation (Meyer & Elsweiler, 2025).

Table 1. Communication Mechanisms of Chatbots and Pro-Environmental Outcomes

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Communication Mechanism	Main Outcome	Mediator/Moderator	Condition of Effectiveness
Problem-solving dialogue	Pro-environmental attitudes; WTP	Communication quality	All users
Anthropomorphic character	Behavioral intention; choice preference	Empathy; anthropomorphism	Users not yet fully committed
LLM-based MI	Motivational readiness; action intention	Initial readiness	Users already committed
Repeated parasocial interaction	Pro-environmental attitudes; climate action intention	PSI (parasocial interaction)	Minimum 3 weeks of interaction

Source: Adapted from Chi (2024); Pataranutaporn et al. (2025); Meyer and Elsweiler (2025); Jang et al. (2025).

4.2 Trust in AI Moderates Effectiveness in a Non-Linear Manner

Chakkambath et al. (2025) show that trust in AI is not a linear prerequisite for the effectiveness of environmental chatbots. Among users with moderate levels of trust, chatbot interaction generated stronger changes in environmentally friendly behavior than among users with very high trust. The underlying mechanism is cognitive elaboration: moderate skepticism encourages users to process messages more deeply and critically, such that messages that survive this elaborative processing are more strongly internalized and less vulnerable to attenuation over time (Chakkambath et al., 2025). Research on the foundations of trust in AI further confirms that trust is built through experiences of consistency, transparency, and respect for user autonomy rather than passive acceptance (Ferrario et al., 2020).

4.3 Systemic Epistemic Bias Threatens Communicative Legitimacy

An analysis of 30,000 chatbot responses on ecological restoration revealed a consistent and systematic pattern of representational bias (Urzedo et al., 2024). The dominance of particular institutions, the neglect of local knowledge, and the tendency toward excessive optimism are not merely technical problems of accuracy, but communication problems related to power and legitimacy. A chatbot that implicitly defines “valid ecological knowledge” as “recommendations from Western academic institutions” reproduces knowledge hierarchies that may marginalize Indonesian local communities, even though such communities often possess rich and highly relevant ecological knowledge of their own (Urzedo et al., 2024).

Justice Dimension	Finding	Representation Percentage
Origin of academic institutions	Dominance of North American and European universities	67% of responses
Representation of low-income countries	Very limited	7% of responses
Local community experience	Almost absent	2% of responses
Indigenous knowledge	Negligible	< 2% of responses

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Technical focus	Planting/reforestation dominant	69% of recommendations
Presentation of outcomes	Excessively optimistic	60% of responses

Source: Adapted from Urzedo et al. (2024).

4.4 VSD Produces More Acceptable and Ethical Design

The application of value-sensitive design (VSD) to LLM-based chatbots for environmental education produced a comprehensive value map, including identity, well-being, human-AI relationships, and sustainability, which were subsequently translated into verified design principles (Nguyen et al., 2025). User involvement, including both students and teachers, in participatory design processes generated values that supported more meaningful technology adoption: chatbots that were "co-designed with users" showed higher levels of engagement and trust than chatbots developed without stakeholder input (Nguyen et al., 2025). This finding supports Fogg's (2002) argument that the credibility of persuasive technology is built through real user experience rather than through the system's technical claims alone.

5. DISCUSSION

5.1 Theoretical Analysis: Extending Framing Theory to AI Dialogue Design

The finding that problem-solving operates through the mediation of communication quality provides strong empirical support for extending framing theory into the domain of chatbot dialogue design (Guenther et al., 2023). Framing theory has traditionally been applied to mass media texts and institutional message production; this study argues that every chatbot conversational design decision, from topic sequencing to the choice of local examples, is a framing decision that influences communication outcomes (Guenther et al., 2023; Entman, 1993). Problem-solving dialogue architecture is, in essence, an implementation of a gain frame that emphasizes solutions and self-efficacy, consistent with framing theory's prediction that gain frames are more effective in encouraging action intentions (Nisbet, 2009).

The finding concerning the limitations of LLMs in responding to ambivalent users adds an important nuance to framing theory: the "solution-action" frame appears to be most effective when audiences have already moved beyond ambivalence and are ready to act (Meyer & Elsweiler, 2025). Framing theory therefore needs to incorporate users' motivational condition as a moderator of effectiveness, a dimension that has largely been absent from climate communication scholarship, which has often treated audiences as relatively homogeneous in terms of action readiness.

The findings on epistemic bias (Urzedo et al., 2024) further strengthen the critique that framing is not merely about message strategy, but also about power. The question of who has the authority to define valid ecological problems and solutions is fundamentally political, and it must be addressed explicitly in communication design rather than being answered implicitly through biases embedded in LLM training data.

5.2 Comparison with Previous Studies: Confirmation, Nuance, and New Contributions

The finding that problem-solving is the dominant predictor is highly consistent with Chi (2024) and is further reinforced by evidence from LLM-based MI research (Meyer & Elsweiler, 2025) and studies of persuasive conversational agents for sustainability (Giudici et al., 2025). This study adds a nuance that is not yet fully developed in previous literature, namely the differential effectiveness of chatbots across users' motivational stages, specifically intention conversion versus motivation construction, which has critical implications for communication segmentation and design (Meyer & Elsweiler, 2025). The study also confirms Jang et al.'s (2025) finding that PSI functions as a unique relational mechanism enabled by conversational formats, while adding the perspective that such relational effects must be managed ethically through VSD principles so that they do not become manipulative (Nguyen et al., 2025).

The findings on non-linear trust (Chakkambath et al., 2025) differ from the dominant assumption in technology acceptance studies that trust functions as a linear prerequisite of effectiveness. This result is consistent with the elaboration likelihood model (ELM), which suggests that elaborative processing produces more durable attitude change, although environmental chatbot literature has not yet explicitly integrated an ELM perspective, making this a promising direction for future theoretical development.

5.3 Applied Communication Implications: The CETA Principles

Taken together, the findings generate four directly applicable CETA principles for public communicators and environmental organizations in Indonesia. First, conversations should be designed as personalized problem-solving facilitation. Each session should begin with the diagnosis of users' specific barriers, such as time, cost, access, or knowledge, proceed by offering two or three context-relevant micro-actions, and conclude with a commitment that can be revisited and verified later (Chi, 2024). The primary design objective should therefore be the quality of the conversational experience rather than the volume of information delivered.

Second, skepticism should be addressed productively rather than defensively. Because moderate trust produces deeper internalization, chatbots should welcome critical questions by presenting traceable evidence, explicitly acknowledging scientific uncertainty, and encouraging independent verification (Chakkambath et al., 2025; Ferrario et al., 2020). Traceability standards should be implemented as mandatory protocols rather than optional design extras (Rillig et al., 2023).

Third, justice audits should be institutionalized as a mandatory quarterly standard. Given the risk of systematically reproducing epistemic bias (Urzedo et al., 2024), all environmental education chatbots should undergo source representation audits using metrics that include geographic diversity, representation of local and Indigenous communities, and balance across technical approaches and perspectives. Indonesian local knowledge, including the ecological wisdom of Indigenous communities and traditional agricultural practices, should be actively integrated rather than silently excluded by systems built primarily on Western training data.

Fourth, communication should be segmented according to motivational readiness. Since chatbots are most effective at converting intention into action among users who are already motivated, environmental organizations need to integrate chatbots into a broader communication ecosystem (Meyer & Elsweiler, 2025). Social media campaigns, community programs, and face-to-face activities can help build initial motivation, while chatbots can then assume the role of converting that motivation into specific and measurable action commitments. For users who remain ambivalent, chatbots should be equipped with motivational dialogue modules based on motivational interviewing principles, including the exploration of ambivalence, reflection on personal values, and gradual commitment-building (Meyer & Elsweiler, 2025; Ajzen, 1991). This segmentation is also demographically relevant in Indonesia: urban Generation Z users who have already been exposed to sustainability narratives through social media are likely to occupy more advanced motivational stages than older age groups or users in areas with more limited access to information, making differentiated dialogue strategies necessary across segments (Schäfer, 2025).

A fifth dimension, often absent from technical chatbot guidelines, concerns investment in ethical conversational persona and long-term relational design. Research on anthropomorphic environmental chatbots suggests that parasocial interaction (PSI) developing through repeated interaction mediates improvements in attitudes and climate action intentions, with stronger effects emerging as the intensity and frequency of interaction increase (Breves & Liebers, 2022; Jang et al., 2025). However, parasocial relationships built without transparency, especially when users are not fully aware that they are interacting with an AI system, raise serious ethical risks of manipulation (Liebers & Schramm, 2019). For this reason, VSD principles require ecological chatbots to identify themselves explicitly as AI systems, respect the boundary between healthy emotional engagement and unproductive dependency, and facilitate users' transition toward real-world action rather than merely sustaining virtual conversation (Nguyen et al., 2025; Fogg, 2002).

A sixth implication is the need to design for active engagement rather than passive information consumption. Research on persuasive technology shows that users who participate actively through decision-making, reflection, and verbal commitment during interaction demonstrate more durable attitudinal and behavioral change than users who merely read or listen (Fogg, 2002; Petty & Cacioppo, 1986). Accordingly, the dialogue architecture of ecological chatbots should be designed to encourage active response through reflective questions that invite value-based introspection, decision scenarios that require users to prioritize concrete actions, and public micro-commitments, such as "I will bring my own shopping bag this week," that can then be revisited in subsequent sessions (Ajzen, 1991).

6. CONCLUSION

This study affirms that AI-based chatbots hold genuine transformative potential as agents of environmental education; however, this potential can only be fully realized when chatbots are intentionally designed as instruments of applied communication intervention rather than merely as channels for delivering ecological information.

The CETA framework developed in this study, comprising four components, namely Credibility/Framing, Empowering Problem-Solving, Trust-Responsive Interaction, and Accountability/Justice-by-Design, integrates climate communication framing theory, the dynamics of trust in AI, epistemic justice, and value-sensitive design (VSD) into a coherent and operationalizable guide for chatbot design and evaluation.

This study makes three main theoretical contributions. First, it extends framing theory explicitly into the micro-domain of chatbot dialogue design by arguing that every conversational architecture decision is a framing decision with measurable communicative consequences. Second, it incorporates the condition of non-linear trust moderation into the effectiveness model of environmental chatbots, thereby enriching technology acceptance theory with a dimension of cognitive elaboration that has largely been absent. Third, it positions epistemic justice as a variable of communicative legitimacy rather than merely an ethical critique, with concrete design implications in the form of mandatory representational audit protocols. Collectively, these contributions open new avenues for research linking communication studies, AI ethics, and technology design within an integrated perspective.

For environmental communication practitioners in Indonesia, this study offers six applied principles that can be directly operationalized: (1) structuring conversations as personalized problem-solving facilitation; (2) responding productively to skepticism through traceability and transparency; (3) institutionalizing quarterly representational justice audits; (4) segmenting communication according to users' motivational readiness; (5) designing ethical and transparent conversational personas; and (6) creating architectures that promote active engagement. These principles may be adapted by the Ministry of Environment,

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environmental NGOs, educational institutions, and public communication agencies seeking to maximize the impact of ecological chatbots in an accountable manner.

The principal limitation of this study lies in its reliance on a synthesis of secondary literature without primary field testing, which restricts the generalizability of the findings across specific operational contexts. The geographic distribution of the sources, which is dominated by Western and East Asian contexts, also limits their direct relevance to Indonesian communities, especially Indigenous and rural communities whose communication dynamics and ecological knowledge systems differ in fundamental ways. In addition, the systematic design of the review, which restricted the synthesis to formally published sources, may have excluded valuable practitioner knowledge embedded in institutional reports and field-program documentation.

7. RECOMENDATTION

Future research should therefore include: (1) field testing of CETA-based chatbot prototypes through randomized controlled experiments in urban and rural Indonesian communities to assess the framework's external validity; (2) six-month longitudinal studies measuring the persistence of pro-environmental behavioral change following chatbot interaction; (3) the development of justice-audit instruments that can be used periodically by non-technical communication teams; (4) cross-cultural comparisons of chatbot persona effectiveness, particularly relational versus instructional personas, across Southeast Asian contexts; and (5) the exploration of how Indigenous Indonesian knowledge, including concepts such as Tri Hita Karana, Sasi, and other forms of local ecological wisdom, can be integrated into environmental chatbot knowledge bases as a concrete response to the epistemic bias identified in this study.

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